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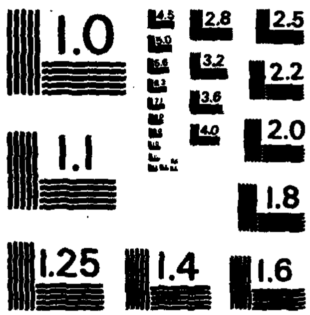

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AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

Structures Technical Memorandum 366

PROPOSED CRASHWORTHINESS REQUIREMENTS FOR THE AUSTRALIAN BASIC TRAINER

by

S. R. [illegible]

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PROPOSED CRASHWORTHINESS REQUIREMENTS FOR THE AUSTRALIAN BASIC TRAINER

by

S.R. SARRAILHE

SUMMARY

A proposal for the crashworthiness requirements for the Basic Trainer was prepared by ARL in response to a request from the RAAF. The requirements, which are based on existing standards, together with some subsequent interpretations and recommendations are collated in this ~~T~~echnical ~~M~~emorandum.

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CONTENTS (contd.)

1. INTRODUCTION

A proposal for the crashworthiness specification for the Basic Trainer was prepared by A.R.L., in response to a request from the RAAF.

A draft based on existing military standards, was sent to the RAAF in June 1981 and is reproduced in Parts 1 and 2 of this memorandum. A.R.L. was subsequently asked to interpret or expand some aspects of the requirements by the Australian Aircraft Consortium (AAC) and the Commonwealth Aircraft Corporation Ltd (CAC) and this was done by discussions and memoranda. These communications (ARL File S500) have been collated with the minimum of editorial change are presented in Parts 3 and 4 of this document.

PART 1. PROPOSED CRASHWORTHINESS REQUIREMENTS

(Prepared in April 1981)

1. General

1.1 Cabin and fuselage

(a) The Structure and equipment surrounding the occupants should withstand the inertia loading shown in Table 1. (Seat and occupant restraint loads are detailed separately).

TABLE 1. CRASH LANDING INERTIA FACTORS

Direction	Load Factor g
Forwards	30
Backwards	11
Downwards	22
Upwards	9
Sideways	9

In the event of an overturn the cabin should withstand a loading equivalent to 4g on the aircraft gross weight applied to the top of the cabin in a representative way. The structure should not deform sufficiently to crush the occupants.

(b) The underside of the fuselage should be designed to minimise earth or water scooping if the aircraft lands with the landing gear retracted.

(c) Cockpit interior surfaces which could be struck by the occupants in crash conditions should not have sharp edges or projections which would be likely to cause injury.

(d) Care should be taken to prevent entrapment of the body and particularly the feet.

1.2 Emergency exit

After a crash it shall be possible for all mobile occupants to evacuate the aircraft in not more than 30 seconds.

1.3 Landing gear

(a) The landing gear should be able to decelerate an aircraft at normal gross weight from a vertical velocity of 6 m/s without allowing the fuselage to contact the ground or the cabin deceleration to exceed 20g.

(b) The landing gear should be arranged so that if it fails it does not penetrate the cabin or rupture fuel tanks.

1.4 Fire prevention

(a) Flammable fluid systems shall be designed to be tolerant to structural distortion such as could occur in a survivable crash.

(b) Flammable fluid systems shall be separated as far as possible from ignition sources and electrical systems.

(Principal reference for 1.1,1.2,1.3 & 1.4, Mil Std 1290[1]).

2. Seats and Occupant Restraints

2.1 Restraint system

The provisions of ASCC Air Std 61/2[2] apply to the restraint system with an occupant with a mass up to 100kg and stature and sizes as indicated by the A.R.L. Anthropometric survey[3]. The strength requirements for the safety harness assembly harness-to-seat, and seat-to-structure, or harness-to-airframe as specified in ASCC Air Standard 61/2[2] are 30g in the forwards, backwards and downwards directions and 15g sideways and upwards. The buckle and end fittings shall withstand misalignment of the strap forces such as could occur in a survivable accident.

2.2 Seats

The seat shall withstand the forces shown in Table 2 without failure at any position in its adjustment range, when the forces are applied in a representative manner e.g. by the ARL pivoted body block. (See Part 3 para. 2.2).

TABLE 2 SEAT DESIGN ULTIMATE FORCES-kN

	Longitudinal	Vertical	Side	Source
Forwards	30	0	0	Air Std 61/2[2]
Backwards	11	0	0	Mil-S-81771A[4]
Downwards	0	18	0	Mil-S-81771A[4]
Upwards	0	9	0	Mil-S-81771A[4]
Forward & Down	9	16	0	New
Forward & Sideways	16	0	9	New

Note: The downwards load of 18kN corresponds to 22g acting on 80%[5] of the occupant's mass to allow for the support to the legs from the feet.

2.3 Seat energy absorption

To protect the spine from excessive loading in the vertical direction, the seat shall be designed to compress, or stroke, in a substantially downwards direction whilst applying a decelerative force to the body and thus absorbing energy.

The stroke shall be the maximum attainable in the space between the seat and the floor but shall not be less than 300mm[6] in the vertical direction (i.e. normal to the aircraft longitudinal and lateral axes).

The decelerative force on the pilot should be the greatest safe value, but to accommodate the probable range of pilot mass with a fixed decelerative force, a value for the force transmitted to the pilot of 11±1 kN is recommended.* The force limiting mechanism should allow for a force of 23 times the weight of the moving parts of the seat to act simultaneously with the 11±1 kN load on the pilot.

The force should be nearly uniform during the stroke but the maximum value must not occur in the first 15% of the stroke. Energy absorbing efficiency, measured by the ratio of maximum energy absorbed (intergral of force with respect to stroke) to the product maximum force times total stroke, expressed as a percentage shall not be less than 60%.

The force transmitted to the body when the cabin is subjected to combined forwards and downwards loading is likely to be influenced by the forward loading. To minimise adverse interaction the locus of the centre of gravity of the seat and pilot as the seat strokes should not be inclined at more than 30° to the vertical axis. The energy absorbing system should be designed to meet the foregoing requirement when the inertia load vector acts in a direction downwards and 30° forwards of the vertical axis.

The stroking mechanism shall not be rendered inoperative by structural deformation that could occur in a crash compatible with the protection provided.

When the seat strokes the restraint system should not loosen or tighten excessively. The seat must not change attitude in a way that would increase the risk of "submarining" under the lap belt, and the seat structure and trim must not trap the occupant or expose the occupant to sharp or jagged edges.

The seat must not stroke or be deformed permanently under any normal flight manoeuvre.

* with 80% of a 50th percentile occupant supported by the seat, 11kN corresponds to 18 g.

2.4 Static tests

Static tests are required to demonstrate strength of the seat and restraint to the loading requirements of Table 2.

Less critical cases may be tested to 66% of the ultimate design force, the most critical case shall be tested to the design ultimate force and failure.

The A.R.L. Articulated body block shall be used. The seat shall be at its highest or most critical position with the stroking mechanism locked.

2.5 Dynamic tests

Dynamic tests are required to demonstrate the performance of the seat, restraint and energy absorbing system, and in particular to show:

(a) that the maximum force transmitted to the torso of a test dummy is 11±1 kN, when the unit strokes through its full travel.

(b) that the energy absorbing efficiency is at least 60%.

The test shall demonstrate that the system is tolerant to airframe distortion.

The maximum velocity change shall be determined.

2.5.1 Dynamic test procedure

The dummy shall represent a 50th percentile occupant (77kg) with 80% of the weight supported by the seat and seat back. A body block wholly supported by the seat and with a mass of 62kg is acceptable provided it has a representative buttock form.

The inertia load vector shall be 30° forwards from vertically downwards.

The seat may be mounted in a section of fuselage or in a representative rig but the rig must not provide better support than the fuselage and must allow for simulation of structural deflection. The deceleration pulse shall be approximately triangular with a peak value in the range 40-50g. The velocity change should be about 12 m/s.

PART 2. SUPPORTING STATEMENTS

1. Occupant Mass

The mass of the clothed occupant should be assumed to be 100kg for strength calculations. For optimization of the energy absorbing seat a median mass should be used (50th percentile) but the range 5th to 95th percentile must be considered. The 11 kN force proposed ensures that the small (5th percentile) occupant is not loaded excessively (i.e. is not loaded to more than 23g) and also provides useful deceleration for the heaviest occupants. Optimization for either of the extremes of mass will reduce effectiveness for the more common sizes of occupant. For vertical loading the seat is assumed to support 80% of the mass of the occupant.

2. Design Forces

The design forces are as specified in Mil-S-81771A[4] except that:

(a) The forward loading has been reduced from 33 kN to 30 kN in accordance with the value in ASCC Air Standard 61/2.[2]

(b) A combined forward and downward loading is introduced. The resultant force of 18 kN is the same as the maximum vertical force and the direction is that specified in the dynamic test procedure of Mil-S-81771A.[4]

(c) A combined forwards and sideways test is introduced instead of the separate load cases on the lap belt and shoulder harness specified in Mil-S-81771A.[4] Resultant load is 18 kN and the direction is that specified in one of the dynamic test procedures of Mil-S-81771A.[4] The separate load procedures of Mil-S-81771A[4] are also acceptable as an alternative to this loading case.

3. Energy Absorption

Both Mil-S-58095[6] and Mil-S-81771A[4] specify an energy absorption requirement with a given velocity change of 15 m/s. The maximum allowable torso deceleration is specified in Mil-S-58095[6] but not in Mil-S-81881A[4] which allows the torso deceleration or operating force to be selected to suit the available stroke. As the objective of this requirement is to limit the force on the spine it is preferable to specify this force, or the torso deceleration, and optimise performance on this basis. Minimum limits on stroke and efficiency should be indicated.

PART 3. INTERPRETATIONS

1. Load Distribution in the Seat and Restraint Harness under Forwards and Downwards Loads.

(The following information was sent to CAC on 24.2.82).

1.1 Introduction

The position of the centre of gravity for the body (pilot) will vary according to the loading condition because of the variable shape of the occupants and non rigid connection to the seat. In addition the distribution of loading between the seat bottom and the restraint harness is not statically determinant, and indeed it changes with time during the deceleration pulse, the direction of the deceleration vector, the stature of the occupant, and the stretch of the restraint under load.

Positions for the centre of gravity and load distributions are recommended based on a study of specifications and the results of tests at ARL and other establishments. A test installation was set up at ARL to represent the Basic Trainer Geometry, and the results are given in Part 3.2.

1.2 Centre of gravity for aircraft balance, i.e. steady '1 g' condition

AvP 970[7] and Mil-S-25073A[8] (USAF) show the body CG 12 and 10.5 inches (305-267mm) above the seat and 10.75 to 11.5 inches (273-292mm) forward of the back rest. This range appears representative. See Fig. 1.

1.3 Centre of gravity under crash loads for the evaluation of seat reactions onto the airframe

Under high inertia loading the body will distort. Downwards loads will pull the arms down but the feet will be supported by the floor rather than the seat. The Crash Survival Design Guide[5,10] suggests that for downwards loads 80% of the body mass be assumed to act 6.5 inches (165mm) from the seat back. Forwards loading uses the full body mass 10.5 inches (267mm) above the seat as shown on Fig. 2. (The loads proposed by ARL take account of these mass proportions).

Since it is considered that some allowance should be made for forwards deflection of the body, it is recommended that:

> The centre of mass of the occupant is assumed to be 200mm in front of the back rest and 267mm above the seat. <u>Assumption 1</u>

1.4 Evaluation of the loads within the seat structure

The loading within the seat assembly will depend on the centre of action of the downward loads onto the seat pan and the magnitude of these loads. If subjected to a downwards load the occupant will tend to slide down the back rest and the component of the load parallel to be back rest will be reacted by the seat pan, at some distance x in front of the Seating Reference Point, SRP, as shown in Fig. 3 For the design of the seat structure it is recommended that:

> The component of load parallel to the seat back rest is assumed to act 200mm in front of the SRP — Assumption 2

The downwards load on the seat pan is generated directly by downwards inertia and indirectly by the forwards inertia and tensions in the restraint system. These tensions can not be determined statically, but there is sufficient empirical evidence to evaluate loads for design purposes. The inclinations of the straps, the seat pan and the back rest to the inertia load vector are important and to simplify the analysis a coordinate system based on the back rest is recommended. This is inclined to the aircraft axis but is approximately parallel to the seat rails (which is of significance for the sliding friction analysis given later). The relative axes and nomenclature used are:

xx	Longitudinal aircraft axis
zz	Downwards aircraft axis
x'x'	"Forwards" axis perpendicular to back rest
z'z'	"Downwards" axis parallel to back rest
P_x, P_z,	Components of inertia load in directions xx and zz
P_x', P_z',	Components of inertia load in directions xx' and zz'
T_L	Load in lap strap (sum of tensions in both straps)
T_S	Load in shoulders strap (sum of tensions in both straps)
F_D	Downwards load on the seat pan (parallel to z'z')
F_{DD}	Down load from P_z'
F_{DI}	Down load from P_x'
θ	Slope of lap belt to x'x'

The effects of any tension in the crutch strap are neglected and the shoulder straps between the shoulder and anchorage are assumed to be parallel to x'x'. The loads onto the body are thus as shown on Fig. 4.

The tension in the lap strap T_L, produced by the 'forwards' inertia force P_x', has a 'downwards' component $T_L \sin \theta$ at the occupants lap. Part of this is reacted by the thighs, which in turn press down on the seat, and part is reacted by the shoulder strap tension, T_S, however this exerts a downwards force on the shoulders so the total downwards load on the body, and hence on the seat, will be $T_L \sin \theta$. It is therefore recommended that:

The downwards load on the seat induced by the forwards load, be assumed to be $T_L \sin \theta$

Assumption 3

Empirical evidence shows that the lap belt load can be as much as 70% of the forward load thus for the lower parts of the seat and restraint assume

$T_L = 0.7\ P_x'$ Assumption 3A

Combining Assumptions 3 and 3A and adding the downwards inertia component P_z' the total down load on the seat is given

$$F_D = F_{DI} + F_{DD}$$
$$= 0.7\ P_x' \sin \theta + P_z'$$

This load should be considered to act 200mm in front of the SRP as in Assumption 2.

Empirical evidence shows that the shoulder strap load is likely to be between 30 and 40% of the forwards load so for design of the upper part of the seat and restraint assume

$T_S = 0.4\ P_x'$ Assumption 3B

These recommendations are summarised on Fig. 5.

(P_x' and P_z' are evaluated from P_x and P_z in the usual way).

2. Static Tests for Load Distribution

(Based on a communication to CAC of 24.2.1982).

2.1 Procedure

The proposed method for estimating load distribution was checked using a rig employing a restraint system from a CT4 Airtrainer, and set up with Basic Trainer geometry on the A.R.L. articulated static test body block. The assembly is shown on Fig. 6 and the body block is detailed in Fig. 7. Load was applied to the body block in

a forward direction, either parallel to the seating surface (P_1) or inclined 10° downwards relative to the seating surface (P_2), (This corresponds to a load parallel to the fuselage datum with typical seat and back rake.)

The applied load, shoulder harness load and the loads at the back and front of the seat were measured, and from the last two measurements the total seat load, F_{DI} and the distance ($\bar{x}$) of its line of action from the seating reference point (SRP) could be evaluated These are as shown on Fig. 5.

2.2 The body block

The dimensions shown in Fig. 7 correspond approximately to the size of a 50th percentile occupant with a tightly fitted belt. The position where load was applied to the body block was derived in a previous study[9] which matched the proportions of the lap and shoulder strap loads to those measured in dynamic tests with a full anthropometric dummy. The distribution of load is typical for dynamic tests. The articulated body block is preferred to the more usual rigid type because the 'thighs' resting on the seat can affect the strap load distribution. If the base of the body block is long it can minimise shoulder loads or if very short (as shown on Fig. 2) can "dig" into the seat and reduce lap strap loads.

2.3 Seat and restraint geometry

This was based on the Commonwealth Aircraft Corporation design for the Basic Trainer. The angle between the back rest and the curved seating surface was taken as 97°. The seating surface was represented by a flat, rigid plate covered by a sheet of stainless steel and a sheet of PTFE to minimize friction between the "seat" and "body". The lap belt was found to slope at approximately 30° to the seating surface. It was also found that the shoulder strap anchorage was 130mm higher than the shoulder of the dummy and about 100mm higher than the minimum recommended in the Crash Survival Design Guide. The assembly was tested with this high position of the straps, but as the proposed method for estimation assumed the anchorage to be about the same height as the shoulders the assembly was also tested with the shoulder strap anchorage level with the shoulder of the body block.

The proposed method also assumes that the negative "g" strap has little effect on the loading and the assembly was therefore tested both without a negative "g" strap and with a negative "g" strap, fitted to the front of the "seat" in a representative position.

2.4 The estimated seat load

The proposed method, Part 3, para. 1.4, gives the seat load

$$F_D = P_z' + 0.7 \cdot P_x' \cdot \sin\theta$$

For the above seat belt and back rest angles

$$\theta = 23°$$

For load applied parallel to the seating surface i.e. 7° to x'x'

$$P_x' = P_1 \cos 7° = 0.99\ P_1$$
$$P_z' = P_1 \sin 7° = 0.122\ P_1$$

$\therefore$ predicted $\quad F_D = 0.39\ P_1$

For load applied 10° down i.e. 17° to x'x'

$$P_x' = P_2 \cos 17 = 0.96\ P_2$$
$$P_z' = P_2 \sin 17 = 0.29\ P_2$$

$\therefore$ predicted $F_D = 0.55\ P_2$

2.5 Test results

Test results are shown on Figs. 8a and 8b. It is seen that the predictions are in close agreement with the results obtained with the low shoulder strap. (squares and crosses) and also that installation of the negative "g" strap made little difference to the loading. Seat loads produced with the high shoulder strap anchorage (circles) were less than predicted, because the upwards slope of the shoulder strap resulted in a smaller 'down load' onto the shoulder. The reduction in the load at the shoulder, Δ, would be:

$$\Delta = T_S \sin \alpha$$

where α is the slope of the shoulder strap relative to the x'x' axis.

Part 3 para. 1.4 indicates that T_S is likely to be between 0.3 P_x' and 0.4 P_x'.

The angle α was approximately 30° in the test installation with the high anchorage position therefore adjusting the prediction to allow for the slope of the shoulder strap and assuming $T_S = 0.3\ P_x$, the value of F_D is reduced by:

$$\Delta = 0.3\ P_x' \sin 30°$$

$\therefore$ approximately 0.15 P_1 or 0.144 P_2

$\therefore$ $F_D = 0.24\ P_1$ or $0.4\ P_2$.

These values are shown on Figs. 8a and 8b as broken lines. Very close agreement with the test results is evident but in most cases, particularly if the anchorages are not so high or if allowance is made for a taller occupant the method given in Part 3 para. 1.3 is considered adequate.

Tension in the shoulder straps was also affected by strap slope and anchorage height. With the low anchorage, the shoulder strap tension T_S ranged from the lowest value of 0.26 P_2 to the highest value of 0.31 P_1, and with the high anchorage, T_S ranged from a low of 0.32 P_2 to a high of 0.36 P_1. The proposed design value of 0.4 P_x' corresponds to 0.38 P_2 or 0.40 P_1 which is slightly greater than the measured values so the proposed design value is conservative.

The position of the line of action of F_D ranged from 180mm to 220mm from the Seat Reference Point and agreement with the proposed value of 200mm is considered satisfactory.

2.6 Conclusion

The proposed method for estimating loading of the seat is satisfactory.

3. Effect of Side Load on Lap Strap Anchorages

(Based on communication to CAC 23.2.1982).

3.1 Evaluation

The proposed case is 16 kN acting forwards together with 9 kN acting sideways, which resolves to 18.4 kN 30° to one side.

The load may be considered to act 200mm in front of the seat back as for downwards loading. Considering the body to be rigid and the lap straps not to slip around the body the forwards components of load at the anchorages on each side of the seats can be found by taking moments about one side e.g. at B as shown in Fig. 9a. This gives the forwards components at A of 12.5 kN and at B of 3.5 kN. Side loading at the anchorages resulting from inclination of the straps would be shared in similar proportions e.g. 7.03 kN at A. This represents an extreme case because the straps would tend to slide around the body and equalise the tension. If the tension loads at A and B are equal the forwards component at A and B would be 8 kN and the sideways components at A and B would be 4.5 kN as shown on Fig. 9b. This is again an extreme case and reality would lie between the two cases. For design purposes it would be conservative to assume that for either anchorage the forwards component could be 12.5 kN together with a sideways component of 7 kN acting towards the centre of the seat or a forward component of 8 kN together with a sideways component of 4.5 kN acting away from the centre of the seat.

PART 4. FRICTION ANALYSIS

This information was communicated to CAC on 12.3.82 together with a spoken explanation. The following text has been amplified.

1. Introduction

The seat, shown diagramatically in Fig. 10 is deflected downwards, controlled by an energy absorber and guided by the rails when and if the cabin is subjected to excessive deceleration, so that the forces on the spine of the pilot can be limited to a safe value. The seat will slide when the inertia force exerted by the mass of the pilot and seat, in the direction parallel to the guide rails, overcomes the resistance of the energy absorber and the friction in the guide bearings. The energy absorber force should be selected to give the highest safe deceleration to the pilot in order to provide the maximum energy absorbing capacity. It follows that unpredictable variation in the bearing friction would degrade the effectiveness of the system because high friction could overload the occupant, or if the energy absorber force is set to give the required occupant deceleration with the maximum friction envisaged, the deceleration could be insufficient in a low friction situation.

As the centre of gravity of the seat and pilot is in front of the seat rails, the loads on the guide bearings, and consequently the sliding friction, will be governed by the downwards, forwards and sideways components of the applied inertia load.

The following analysis was made to investigate the sliding friction and the variation in friction with the range of loading conditions.

2. Procedure and Nomenclature

The seat geometry, taken from the CAC drawing current at the time of the analysis, is shown on Fig. 10, the centre of gravity is assumed to coincide with the centre of gravity for the occupant as recommended in Part 3 para. 1.2

The loads on the bearings are assumed to be substantially fore and aft. The sideways component would be small and have a negligible effect on the magnitude of the resultant load. The two lower bearings were assumed to react the moment from the side load, upper bearing loads are assumed equal. The forces were resolved into axes parallel and perpendicular to the seat rails. The nomenclature used is as follows:

A_1 A_2	upper bearings	
B_1 B_2	lower bearings	
x	longitudinal axis parallel to fuselage datum	aircraft axes
y	sideways axis perpendicular to fuselage datum	aircraft axes
z	downwards axis perpendicular to fuselage datum	aircraft axes

x'	"forwards" axis perpendicular to seat rail)	seat rail axis
y'	"sideways" axis perpendicular to seat rail)	
z'	"downwards" axis parallel to seat rail)	
P	Applied inertia force	
$P_x' P_y' P_z'$	components in x' y' z' directions	
N	Bearing loads	
N_{A1} N_{A2} N_{B1} N_{B2}	upper and lower bearing loads	
F_R	sliding friction $= \mu \Sigma N$	
μ	coefficient of friction	
F_S	total sliding force $= P_z'$ when seat slides	

3. The Analysis

The upper and lower bearing loads N_{A1} N_{A2} N_{B1} and N_{B2}, shown on Fig. 11, may be found by taking moments. As the entire sideway moment due to P_y is assumed to be reacted by N_{B1} and N_{B2}, $N_{A1} = N_{A2}$ and the combined effect $N_{A1} + N_{A2} = N_A$

$$N_A = 0.12P_x' + 0.83P_z' \tag{1}$$

$$N_{B1} = 0.44P_x' - 0.42P_z' + 2.6P_y' \tag{2}$$

$$N_{B2} = 0.44P_x' - 0.42P_z' - 2.6P_y' \tag{3}$$

The friction force

$$F_R = \mu\{|N_A| + |N_{B1}| + |N_{B2}|\} \tag{4}$$

F_R can be expressed in terms of P_x', P_y', P_z' or the proportion of the sliding force due to friction, $\frac{F_R}{F_S}$ may be expressed in terms of $\frac{P_x'}{P_z'}$ and $\frac{P_y'}{P_z'}$. These ratios indicate the directions of the applied load vector.

If the side load P_y' is zero

$$N_{B1} = N_{B2} = (0.44P_x' - 0.42P_z')$$

$$\therefore \quad N_{B1} + N_{B2} = N_B = (0.88P_x' - 0.83P_z')$$

$$F_R = \mu\{|N_A| + |N_B|\} \tag{5}$$

If $\frac{P_x'}{P_z'} = 0.94$, $N_B = 0$ and F_R is a minimum which occurs if the applied load vector passes through the upper bearing as shown AC on Fig. 11.

$$\frac{F_R}{P_z'} = \mu\ 0.94$$

If the vector is more "downwards" than AC Fig. 11 $\frac{P_x'}{P_z'}$ is less than 0.94 and

$$\frac{F_R}{P_z'} = \mu(1.66-0.76\ \frac{P_x'}{P_z'}) \tag{6}$$

If the vector is more "forwards" than AC Fig. 11

$\frac{P_x'}{P_z'}$ is greater than 0.94

$$\frac{F_R}{P_z'} = \mu\ \frac{P_x'}{P_z'}\ .$$

The resulting variation in $\frac{F_R}{P_z'}$ with $\frac{P_x'}{P_z'}$ is shown for $\mu = 0.2$ in Fig. 12a.

A side load, P_y', will result in unequal loads N_{B1} and N_{B2} but if the side load is small, N_{B1} and N_{B2} will act in the same direction, and the inequality will not increase the friction F_R so that the values given by (6) and (7) will apply. The boundary condition is

$$P_y' = \frac{N_{B1}+N_{B2}}{5.2}$$

If the side load is greater than this it will dominate the friction and

$$F_R = \mu(N_A + 5.2P_y') \tag{8}$$

Values for $\frac{F_R}{P_z'}$ are shown on Fig. 12a for several values of $\frac{P_y'}{P_z'}$ and $\frac{F_R}{P_z'}$

is plotted against $\frac{P_y'}{P_z'}$ on Fig. 12b.

It is seen that the minimum friction is about 20% of the sliding load but that the direction of the load vector, and particularly a sideways component, can result in much higher friction, for example, a sideways component of 0.25 of the downwards load would result in the friction being about 45% of the total sliding force.

If the energy absorber force, E, is selected to give the design sliding force F_{SD} at an intermediate friction say $\frac{F_R}{P_z'} = 0.3$

$$F_{SD} = E + 0.3\ F_{SD} \quad (F_S = P_z' \text{ when the seat slides})$$

$$E = 0.7\ F_{SD}.$$

with minimum friction this would result in a sliding force

$$F_S = 0.7\ F_{SD} + 0.2\ F_S$$

$$F_S = 0.9\ F_{SD}$$

or with friction $\frac{F_R}{P_z'} = 0.45$

$$F_S = 1.3\ F_{SD}$$

If F_{SD} is selected to produce a 'safe' deceleration of 22g on a light (60kg 5th percentile) pilot, all heavier pilots (i.e. 95% of pilots) will receive less than 22g, but at 1.3 F_{SD} the 5th percentile pilot would receive an injurious 29g and only pilots weighing more than 1.3x60 = 80kg would receive 22g or less. This would protect less than 50% of pilots (Mass of the 50th percentile pilot is 74kg and the 95th percentile mass is 91 kg). A side component of about 0.3 would give a sliding force of 1.5 F_{SD} and this would only protect the heaviest 5% of pilots. Whilst the side component has most influence on the friction, the forwards component has secondary importance. The effects of both are shown on Figs. 13a and b which plots the forward and sideways loading combinations which will protect 95%, 50% and 5% of pilots. The load components are expressed relative to the seat rail axes in Fig. 13a but they have been resolved to aircraft axes in Fig. 13b.

The energy absorber force could have been selected to suit a greater friction and this would have reduced the force in the higher side load conditions, but it would have reduced the energy absorbing capacity in low friction cases.

It is seen that quite small side forces produce serious increases in the sliding force. The effect could be reduced by using bearings with a lower friction coefficient. Variability in the coefficient could further increase variability in the sliding force and would further degrade the performance. Bearings with low and consistent friction properties are required.

It was recommended that the high friction resulting from side loads could be reduced by mounting the seat rails further apart. The analysis was repeated with the lower bearings assumed to be 350mm apart and the increased capacity to accept side load for a given increase in sliding load is shown in Figs. 14a and b. It was also suggested that three short rails could replace the two long rails shown in Fig. 10, two rails would be provided for the two lower bearings and a single central rail for the upper bearing.

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9. S.R. Sarrailhe, The Strength of Occupant Restraint Systems in Light Aircraft. Structures Report 375, Aeronautical Research Laboratories, Melbourne, 1979.

* 10. Crash Survival Design Guide, US Army Research and Technology, Technical Report TR 79-22A. Fort Eustis, Virginia, 1980.

* Reference 10 is an updated edition of Ref. 5 - points referred to were essentially the same in both editions, both are referred to because the proposed specification, Parts 1 and 2, were communicated to the RAAF before Ref. 10 was available. Fig. 2 was taken from the later edition.

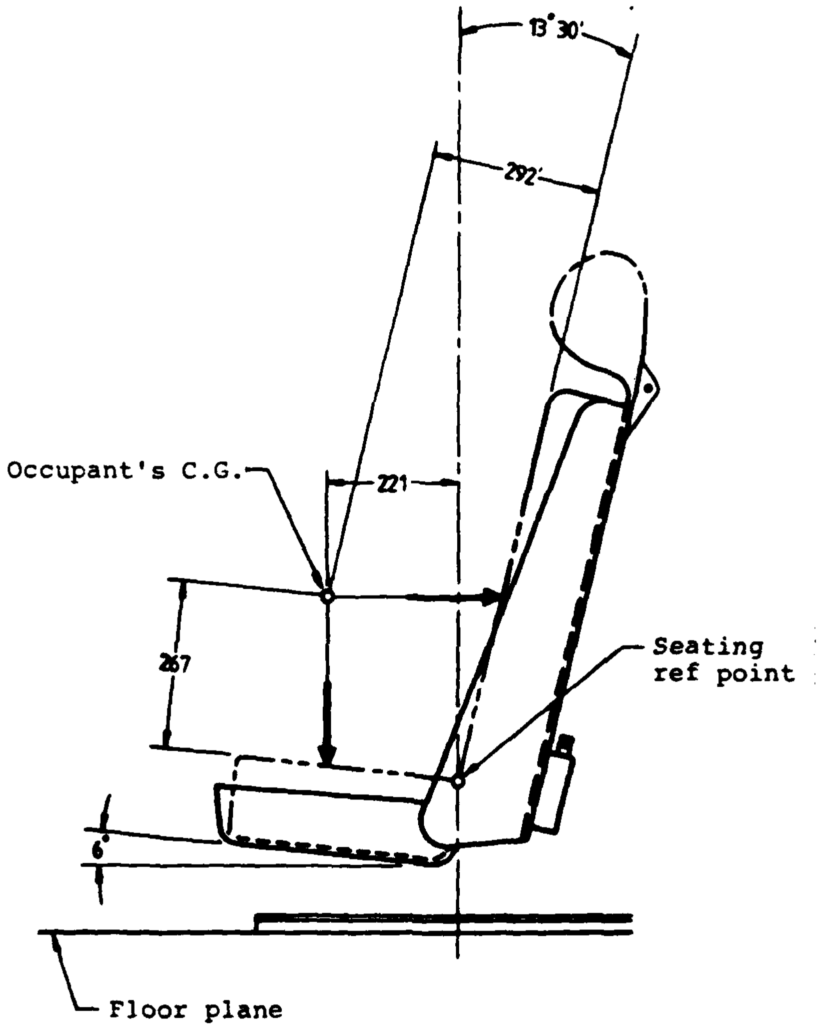


FIG. 1 OCCUPANT CENTRE OF GRAVITY
(DIMENSIONS IN mm)
(FROM MIL-5-25073A (USAF))

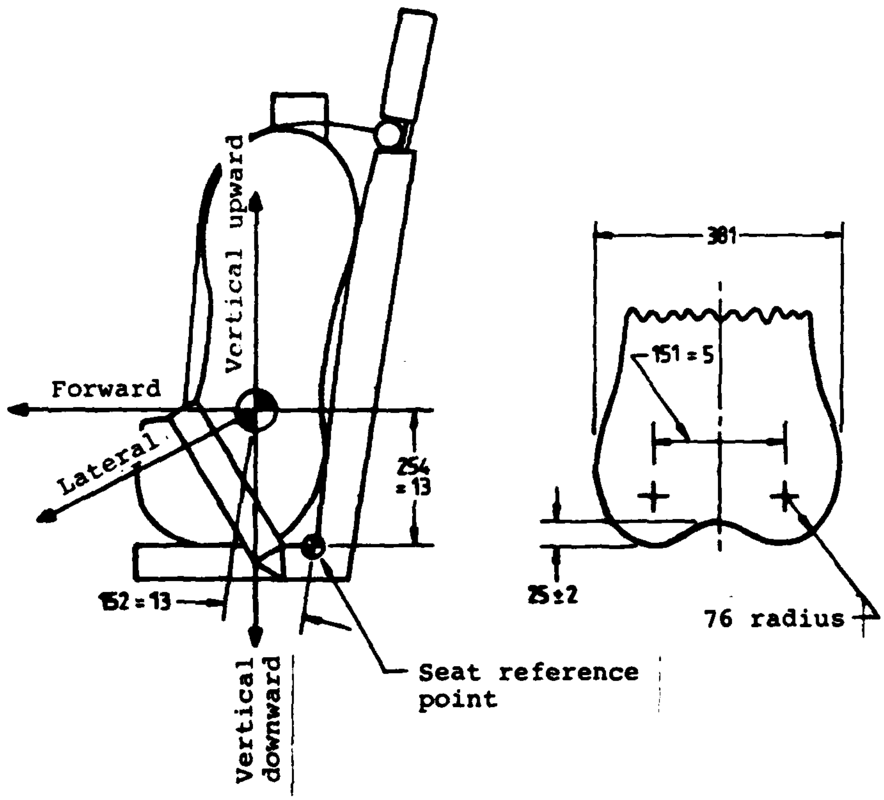


FIG. 2 STATIC LOAD APPLICATION POINT AND CRITICAL BODY BLOCK PELVIS GEOMETRY RECOMMENDED IN THE CRASH SURVIVAL DESIGN GUIDE.[18] (DIMENSIONS CONVERTED TO mm).

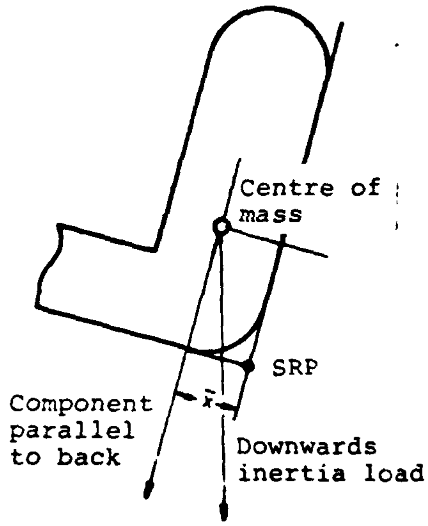


FIG. 3 POSITION OF 'DOWNLOAD' ON SEAT PAN.
BODY WILL LOAD SEAT $\bar{x}$ IN FRONT OF SRP
EVEN IF INERTIA LOAD VECTOR IS CLOSE TO SRP.

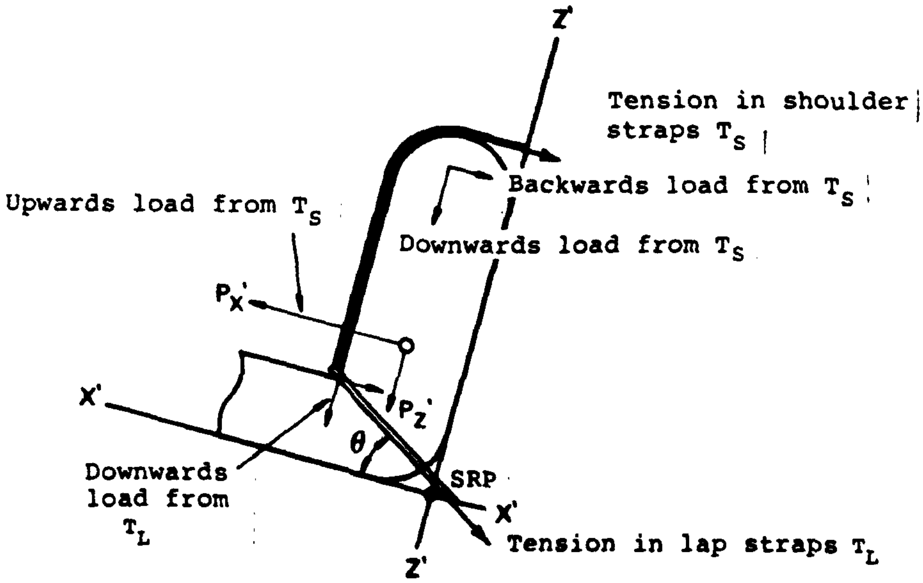


FIG. 4 LOADS ONTO THE BODY
SLOPE (θ) OF LAP STRAP (TENSION T_L)
RESULTS IN DOWNLOAD ON SEAT(= T_L sin θ)

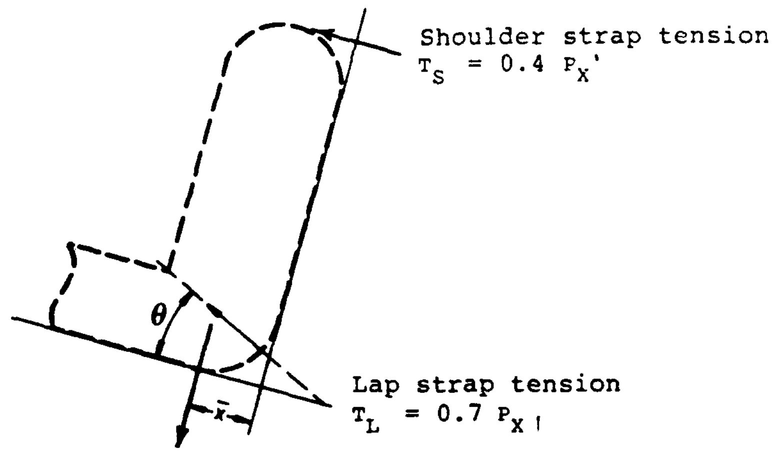


FIG. 5 RECOMMENDED LOADS ONTO SEAT

Note P_X' P_Z' components of inertia load
perpendicular and parallel to back rest

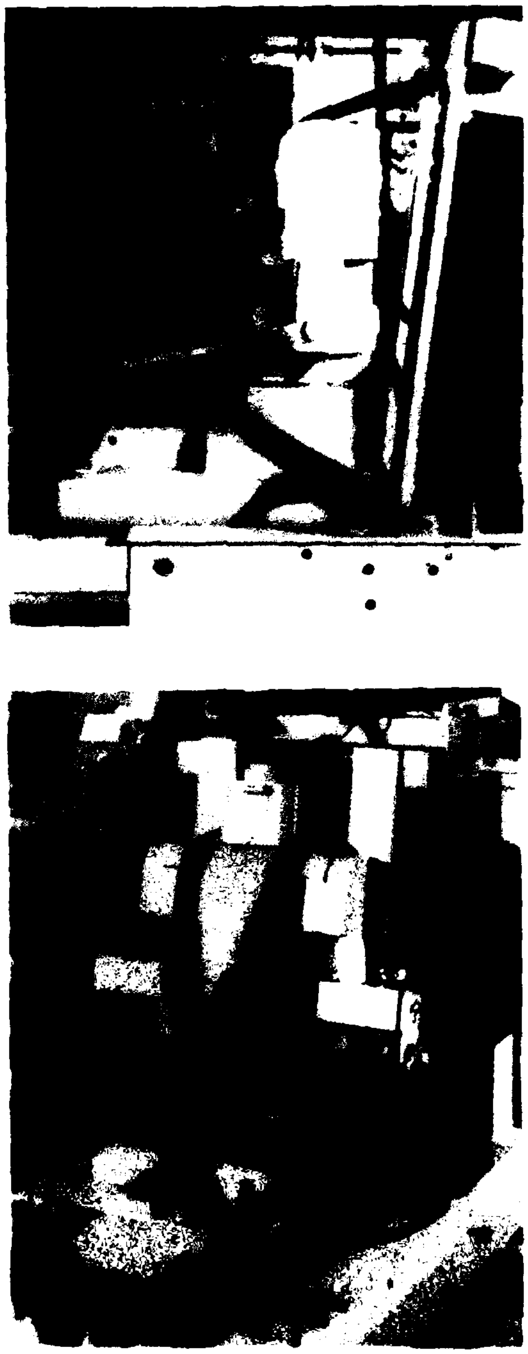


FIG. 6 THE ARTICULATED BODY BLOCK AND TEST ASSEMBLY

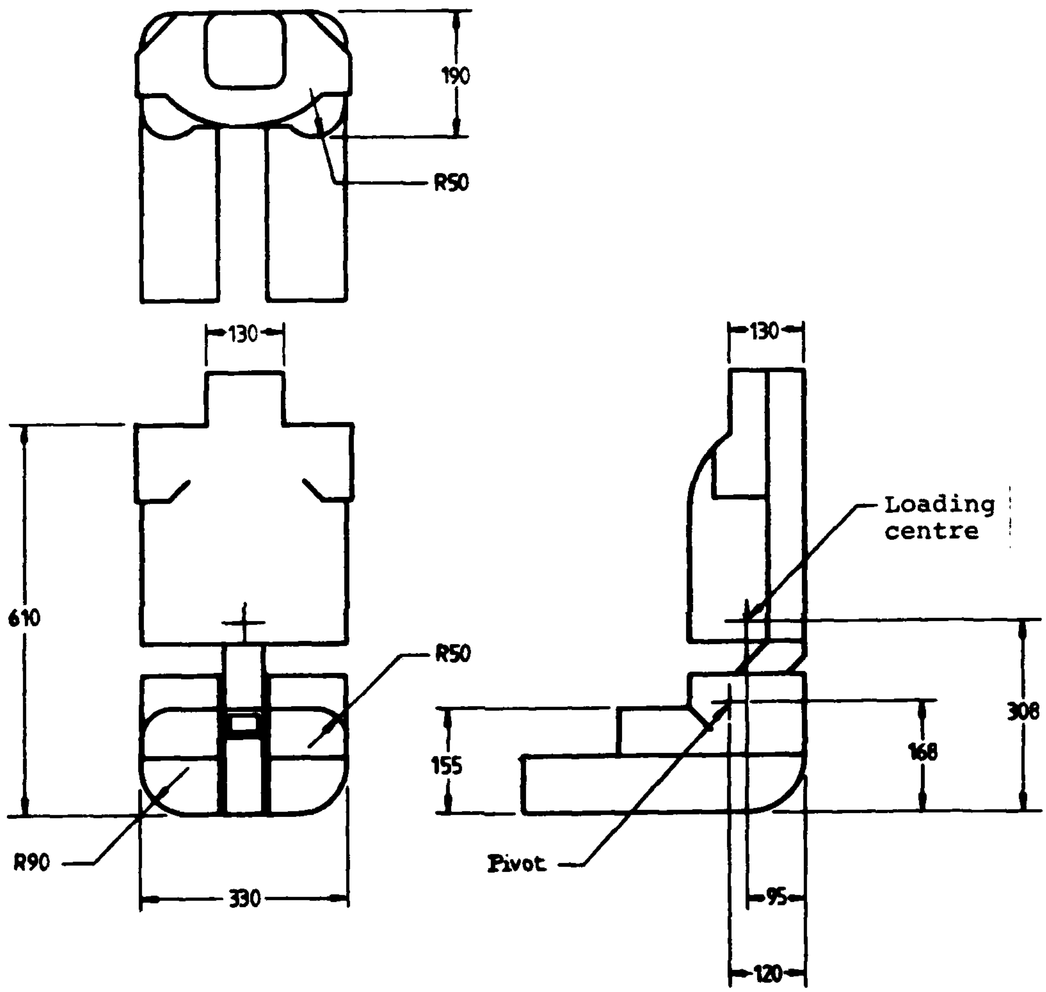
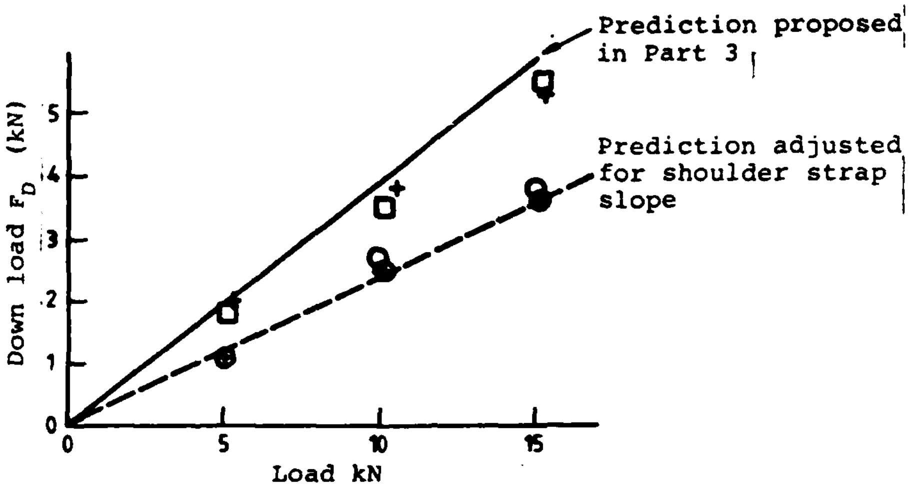
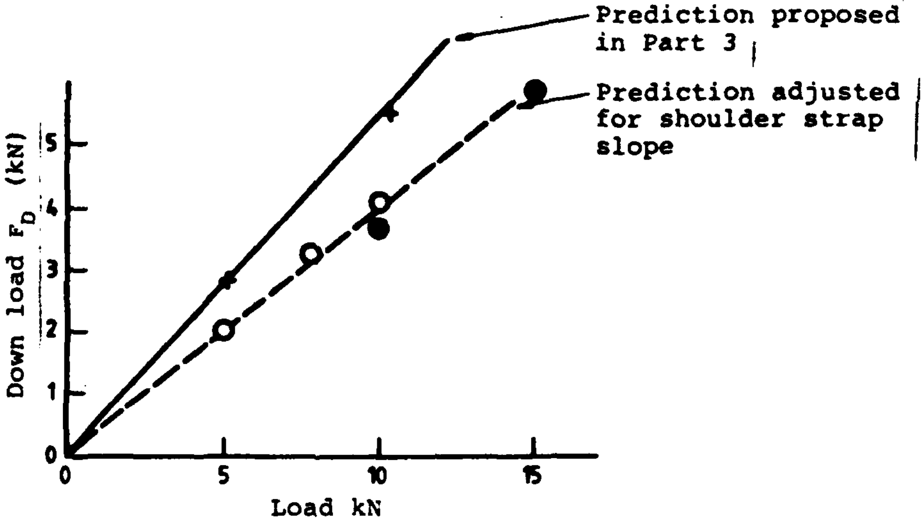


FIG. 7 ARL ARTICULATED BODY BLOCK.
(DIMENSIONS IN mm)



(a) Forward load horizontal (P_I)

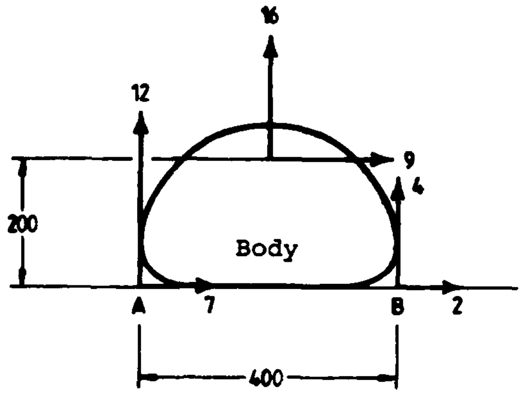


(b) Forward load 10° below horizontal (P_Z)

Key
□ - Low shoulder strap-with neg. 'G' strap
✚ - Low shoulder strap-no neg. 'G' strap
⊕ - High shoulder strap-with neg. 'G' strap
○ - High shoulder strap-no neg. 'G' strap

FIG. 8 DOWNLOAD ON THE SEAT INDUCED BY FORWARD LOAD

Note Full line - proposed method of prediction
Broken line - prediction adjusted to allow for high shoulder strap



9 (a) Anchorage loads based on moment balance

9 (b) Anchorage loads with equal strap tension

FIG. 9 EFFECT OF SIDE LOAD ON LAP STRAP ANCHORAGES, A AND B (LOADS IN kN)

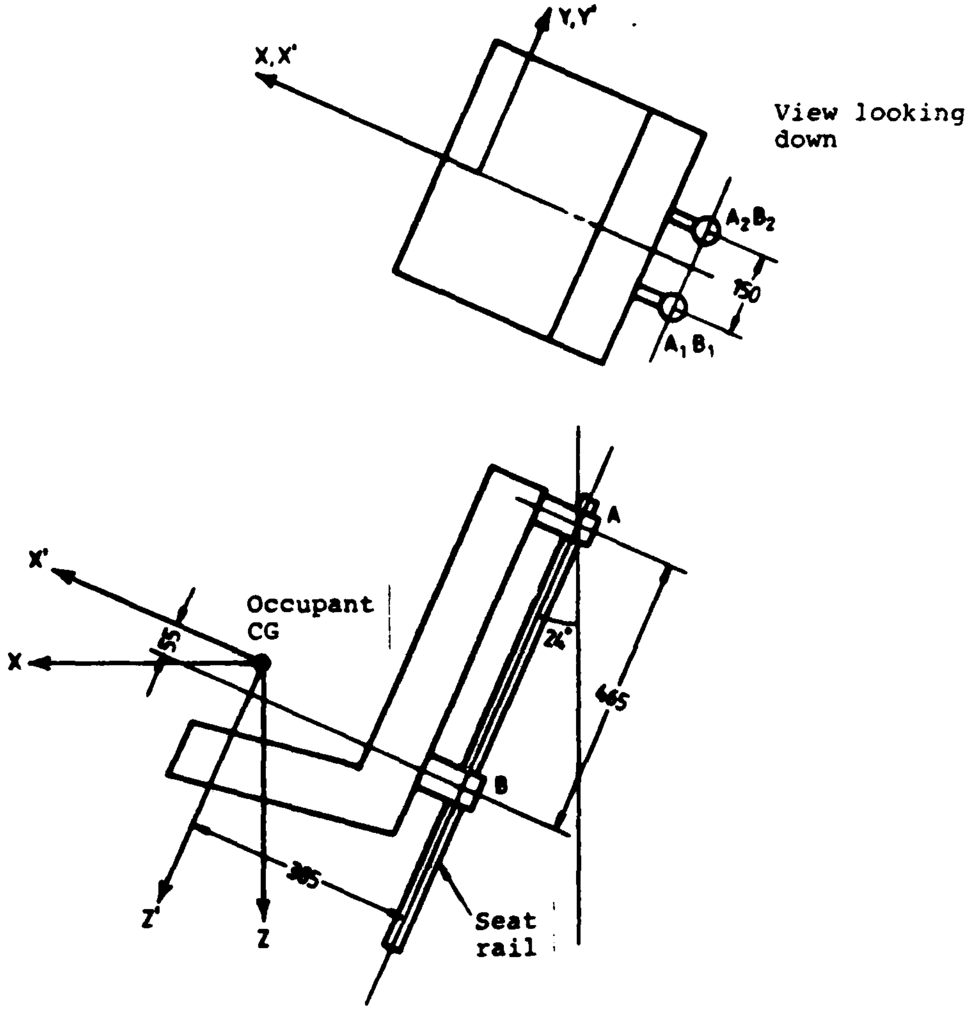


FIG. 10 DIMENSIONS OF CAC SEAT. (mm)
X,Y,Z. Parallel and perpendicular to aircraft axes
X' Y' Z' Parallel and perpendicular to seat rails

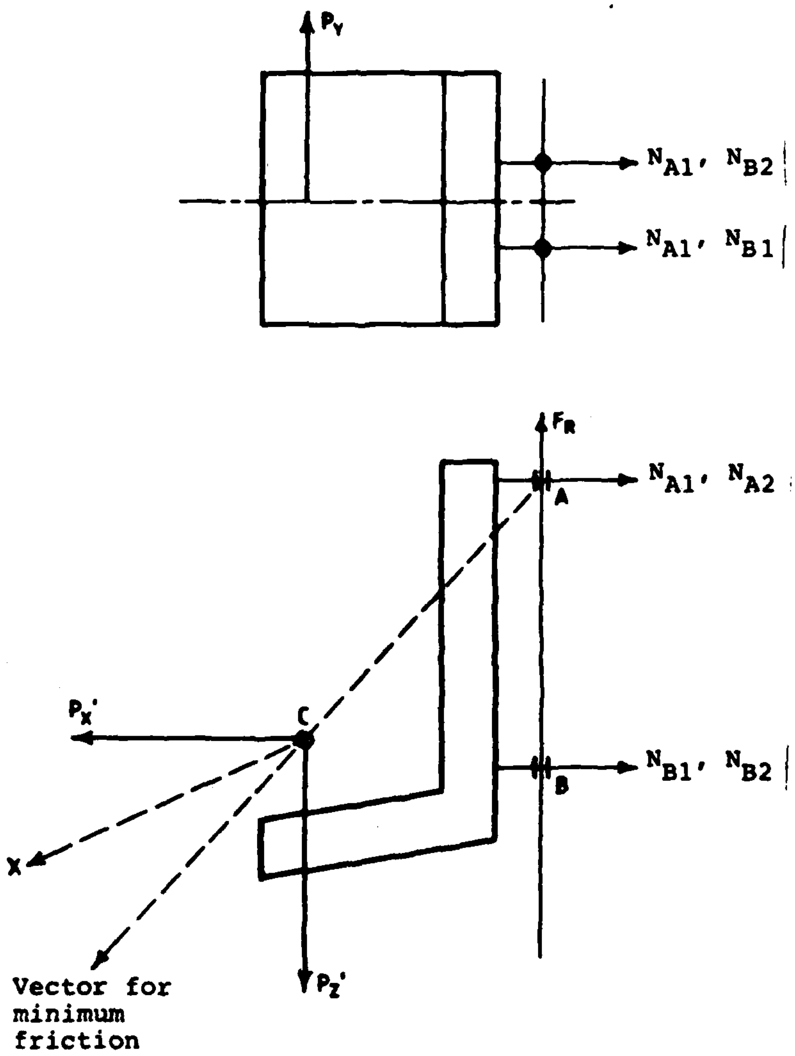
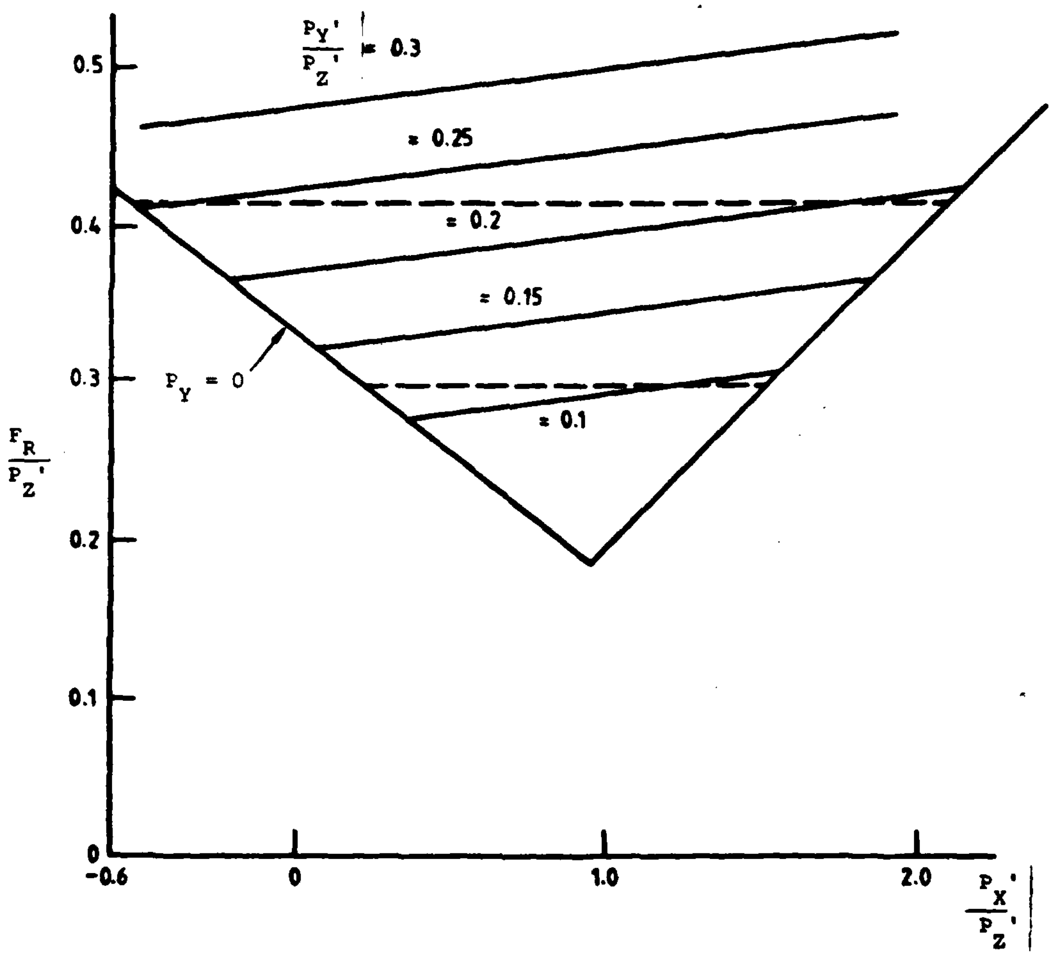


FIG. 11 APPLIED FORCES AND BEARING LOADS



F_R = Friction

P_Z' = 'Downwards' load = Sliding force when seat slides

P_X' = Forwards load

P_Y' = Sideways load

μ = 0.2

FIG. 12(a) EFFECT OF FORWARDS LOADING ON SLIDING FRICTION

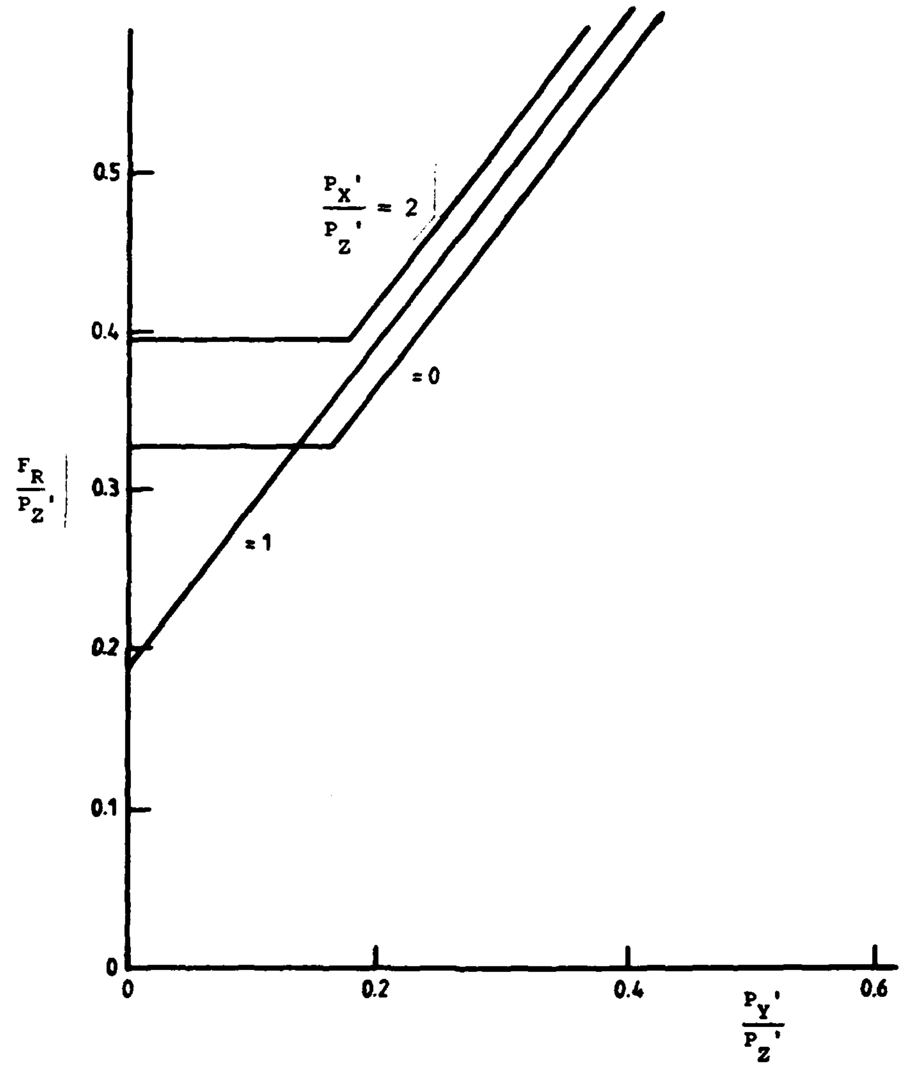
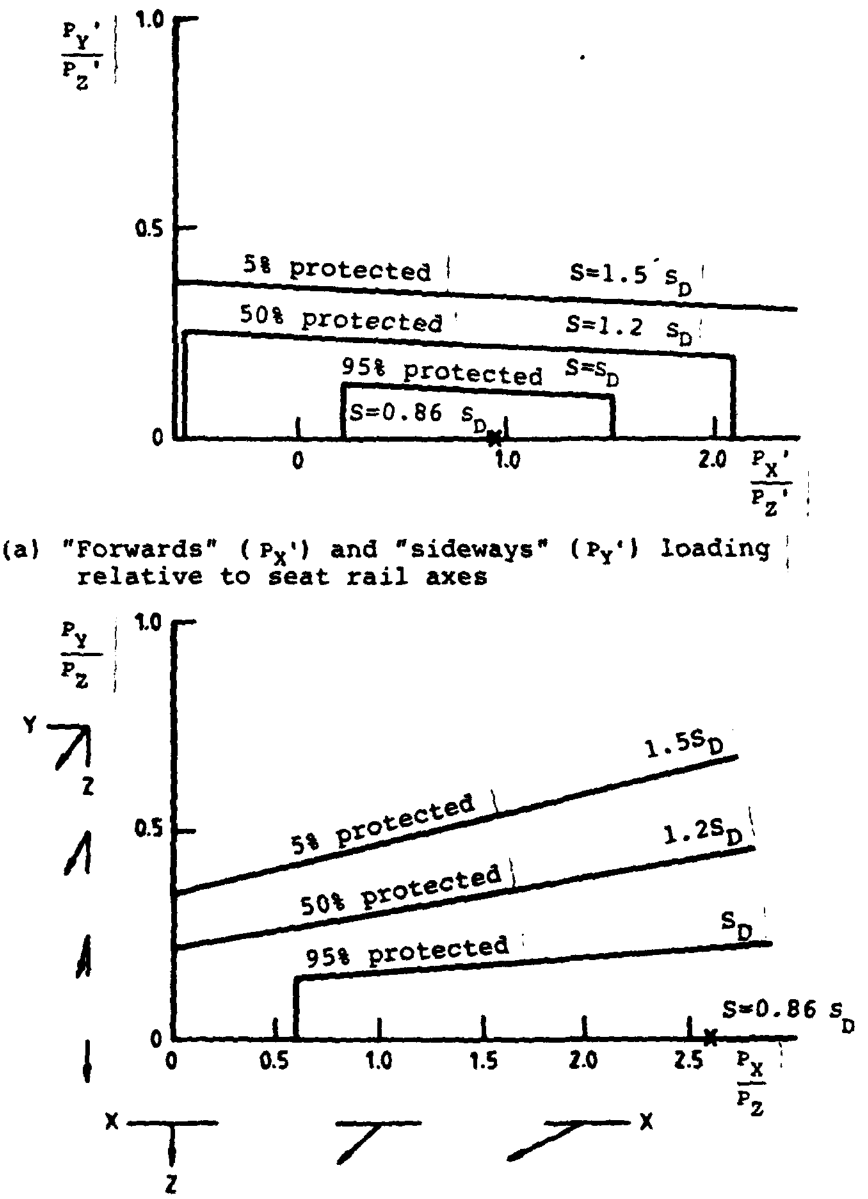


FIG. 12(b) EFFECT OF SIDE LOAD ON SLIDING FRICTION



(a) "Forwards" (P_X') and "sideways" (P_Y') loading relative to seat rail axes

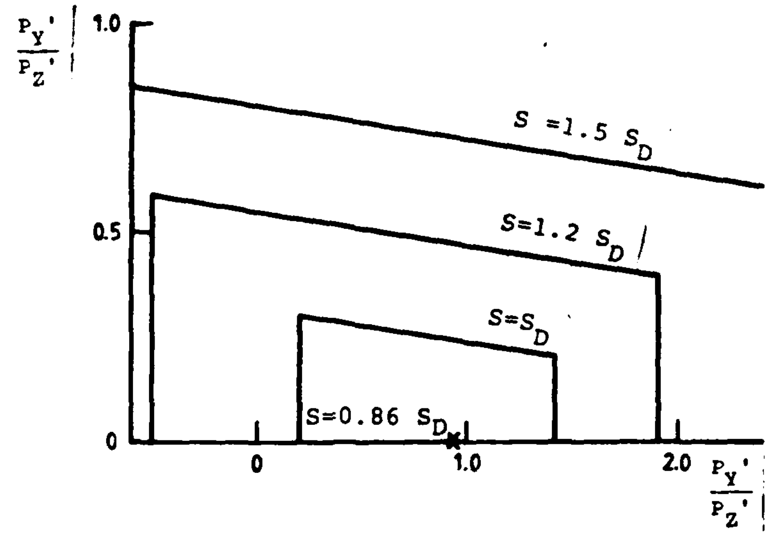
(b) Forwards (P_X) and sideways (P_Y) loading relative to aircraft axes

S = Sliding load

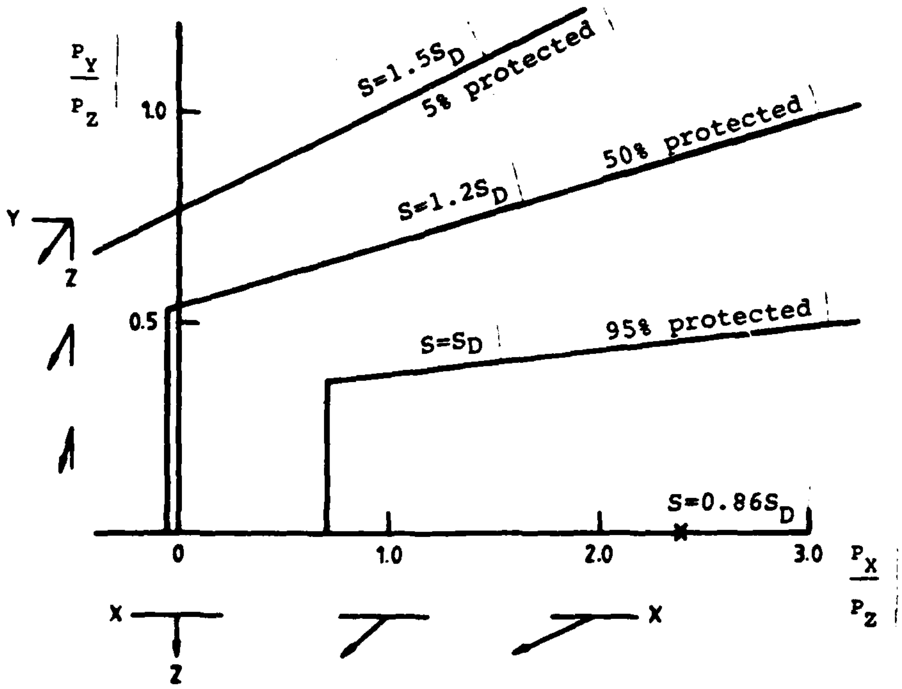
S_D = Design sliding load

μ = 0.2

FIG. 13 SLIDING LOAD - CAC SEAT GEOMETRY



(a) "Forwards" (F_X') and "sideways" (P_Y') loading relative to seat rail axes



(b) Forwards (P_X) and sideways (P_Y) loading relative to aircraft axes

S = Sliding load

S_D = Design sliding load

μ = 0.2

FIG. 14 SLIDING LOAD - RAILS 350 mm APART

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16. Abstract

A proposal for the crashworthiness requirements for the Basic Trainer was prepared by ARL in response to a request from the RAAF. The requirements, which are based on existing standards, together with some subsequent interpretations and recommendations are collated in this Technical Memorandum.

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